LABORATORY Spotlight
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Fiber Tract Mapping with Magnetic Resonance Diffusion Tensor Imaging

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Fundamental advances in understanding biology require detailed knowledge of structural and functional organization in the living system. This is particularly important in the nervous system where anatomical connections determine the information pathways and how this information is processed. Our current understanding of the nervous system is incomplete because of a lack of fundamental structural information necessary to understand function.

Recently measurements of water translational self-diffusion with magnetic resonance imaging methods have been used to study the structural connectivity within whole living organisms. Water movement through tissue is restricted by the microscopic structure of the cellular environment, where the cell membrane is the most effective boundary to motion. In nervous tissue, axonal membranes mainly restrict the diffusion-driven motion of water resulting in anisotropic diffusion. In highly organized nervous tissue, like white matter in brain, diffusion anisotropy can be used to visualize fiber tracts. Recently, MR methods[1] have been developed to measure the tensor of water diffusional motion. We have applied these methods to the study of the spinal cord[2] and have extended this work to image the spatial distribution of two rates of diffusion[3] reflecting intracellular and extracellular processes. These methods provide a complete characterization of the restricted motion of water through the tissue that can be used to infer tissue structure and hence fiber tracts. By tracking the direction of fastest diffusion, non-invasive fiber tracking of the brain and spinal cord can be accomplished. Fibers tracks may be constructed by repeatedly stepping in the direction of fastest diffusion. The direction along which the diffusion is dominant corresponds to the direction of tensor eigenvector corresponding to the largest eigenvalue.

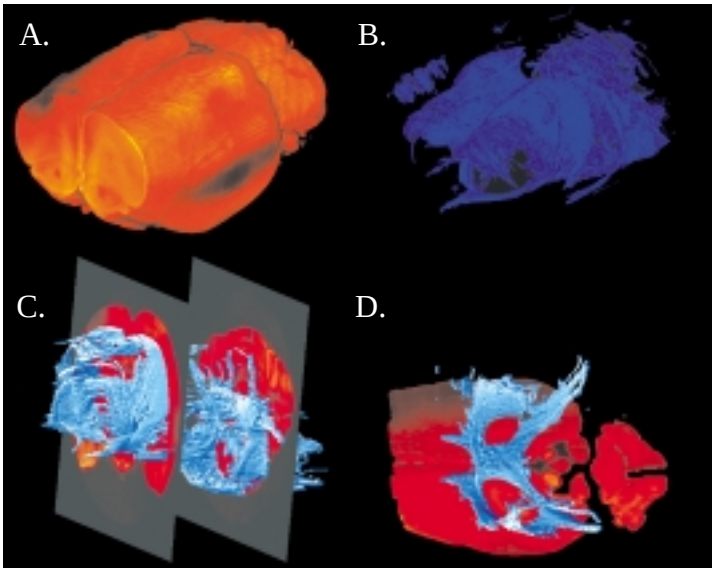

Figure A. Three-dimensional MR image visualization of the rat brain.
Figure B. White matter fiber tracts derived from a measure of the diffusion tensor of water motion through the brain.
Figure C. Detailed view of the fibers relative to the MR image of the brain (viewed from the side).
Figure D. Detailed view of the fibers relative to the MR image of the brain (viewed from below).

An example of white matter fiber track mapping in rat brain is shown in the figure. The results were obtained using the 17.6 T, 89 cm bore magnet Bruker Avance system at the UF McKnight Brain Institute. The specimen is an excised fixed normal rat brain. Because of the effect of the fixative (4 % formaldehyde solution) on the T_2 relaxation of water,[4] the specimen was first washed then imaged in a phosphate buffered saline solution. The diffusion tensor was calculated from a data set of 28 images; four diffusion-weighting gradient strengths in seven directions (x, y, z, xy, xz, yz, xyz). Part A is a three-dimensional MR image visualization of the rat brain. Part B shows the white matter fiber tracts derived from a measure of the diffusion tensor of water motion through the brain. More detailed views of the fibers relative to the MR image of the brain are shown in Parts C (viewed from the side) and D (viewed from below). The fiber-tracking algorithm starts from a voxel center and proceeds in the direction of the major axis of the diffusion

ellipsoid. Tracking continues along the direction defined by the weighted-average of the diffusion directions around the fiber direction. Tracking stops when a measure of diffusion crosses a threshold, i.e., a loss of anisotropy in diffusion.

This scheme for fiber tracking, however, is resolution dependent since the MR data only reflects average fiber orientation within a voxel. Small fibers adjacent to each other may not be distinguished. Moreover, this fiber-tract-mapping scheme does not handle branching fiber structures. More recently, there have been some attempts at changing the standard diffusion tensor model by using a high angular resolution diffusion weighted acquisition to investigate voxels containing multi-directional fibers.[5] This type of spherical sampling addresses the issue of how fiber populations add and may provide a method for discriminating crossing fiber structures. This is a promising approach for addressing the effects of resolution in these MR images and we are currently investigating this in our work.

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[2] Inglis, B.A., Yang, L., Wirth, III, E.D., Plant, D., and Mareci, T. H., "Diffusion Anisotropy in Excised Normal Rat Spinal Cord Measured by NMR Microscopy," *Magn. Reson. Imag.*, **15**, 441-450, (1997).

[3] Inglis, B.A., Bossart, E.L., Buckley, D. L., Wirth III, E.D. and Mareci, T.H., "Visualization of Neural Tissue Water Compartments using Biexponential Diffusion Tenor MRI," *Magn. Reson. Med.*, **45**, 580-587, (2001).

[4] Bossart, E.L., Inglis, B.A., Silver, X.S., and Mareci, T.H., "The Effect of Fixative Solutions in Magnetic Resonance Imaging," In preparation for submission to *Magn. Reson. Med.* (2001).

[5] Frank, L.R., "Anisotropy in high angular resolution diffusion-weighted MRI," *Magn. Reson. Med.*, **45**, 935-939 (2001).